Abstract

Current research suggests that stressors in the Neonatal Intensive Care Unit (NICU) environment may lead to developmental problems for these infants evident later in life. Among these NICU stressors is exposure to increased noise levels. Research studies suggest that increased noise levels experienced by preterm infants correlate with changes in heart rate, respiratory rate, blood pressure, and oxygen saturation. Therefore, the purpose of this study was to determine the impact of reducing alarm noise and implementing a daily 2-hour Quiet Time in decreasing noise levels in a Level IV NICU. A study was conducted to compare noise levels before and after two noise reduction interventions. Hourly ambient sound pressure levels (i.e., Leq, L10, and Lmax) were measured using a Quest 2900 Sound Level Meter in two patient rooms and a staff area. Measurements were taken at baseline, after reducing alarm settings on feeding pumps and educating nursing staff on reduction of IV pump alarms, and again after a daily 2-hour Quiet Time was implemented. Measurements were compared to recommended guidelines for noise in NICUs. Descriptive statistics and *t*-tests were used to compare reductions in post-intervention noise levels. Feeding and IV pump alarm reduction interventions were not found to reduce noise levels in patient rooms or in the staff area and implementation of a 2-hour daily Quiet Time did not reduce noise levels in patient rooms. However, there was a decrease in noise levels in the staff area following implementation of a 2-hour daily Quiet Time. Feeding and IV pump alarms, along with staff-generated noise were not found to be major noise contributors in patient rooms in the NICU. These findings suggest that feeding and IV pump alarms may not be major noise contributors. Further research is needed to identify major noise contributors and to determine effective and low-cost intervention strategies to reduce noise in the NICU environment.

Background

In recent decades the survivability of very low birthweight (VLBW) neonates has greatly improved. However, research suggests that as these infants grow older and begin school they have an increased incidence of cognitive and neurological impairment (Marlow et al., 2005). Findings suggest that stressors in the neonatal intensive care unit (NICU) environment may be contributing to some of these developmental problems (Perlman, 2001). Reported NICU stressors include bright lights, increased noise levels, and healthcare provider interaction with the infant (Perlman, 2001). Increased noise levels, in particular, can cause immediate physiological changes including changes in heart rate, blood pressure, respiratory rate, and oxygen saturation (Wachman & Lahav, 2013). There is a growing focus on controlling these environmental risk factors and implementing interventions that support developmentally appropriate care for preterm infants in the NICU, in hopes of reducing their negative impacts on neonatal health and neurological development. There is also a patient safety focus by The Joint Commission on reducing alarm noise and fatigue in the hospital setting (The Joint Commission, 2013).

Increased noise levels are often a problem in the NICU and can result from equipment (ventilators, etc.), alarms, staff conversation and activities, and crying of surrounding infants (Byers et al., 2006). The American Academy of Pediatrics (AAP) Committee on Environmental Health recommends that sound levels in the NICU not exceed 45 decibels (dB) (1997). The 8th edition of recommended standards for newborn ICU design echoes the AAP recommendations and provides more specific standards for noise (White et al., 2013). These recommended standards state that infant rooms should not exceed an hourly Leq (average sound pressure level) of 45 dB, hourly L10 (sound level exceeded 10% of the time) of 50 dB, and Lmax (maximum sound pressure level) of 65 dB, all using the A-weighted scale, slow response (White et al.,

2013). In staff and family areas, the recommended standards state sound levels should not exceed an hourly Leq of 50 dB, hourly L10 of 55 dB, and Lmax of 70 dB, also using the A-weighted scale, slow response (White et al., 2013). It should be noted that these recommended standards were reviewed and supported by the AAP section of Perinatal Pediatrics (White et al, 2013).

Health Effects of Increased Noise on Preterm Neonates

Many studies have shown that sound levels in the NICU often exceed the recommended levels (Wachman & Lahav, 2010). Preterm infants are more vulnerable to increased noise levels due to their reduced autonomic and self-regulatory mechanisms and inability to filter and process noisy stimuli (Zahr & Balian, 1995). These increased sound levels could be contributing to adverse health effects, though the connection between excessive noise and neurological outcomes has not been well established (Wachman & Lahav, 2010). Research studies suggest that increased noise levels experienced by preterm infants correlate with changes in heart rate, respiratory rate, blood pressure, and oxygen saturation (Jurkovicova & Aghova, 1989; Long et al., 1980; Wharrad & Davis, 1997; Williams et al., 2009). However, some of these studies provide conflicting evidence of these changes and many were done over two decades ago, with very few recent studies. The most current study by Hassanein and colleagues (2013) measured sound levels in the NICU and assessed preterm infants and term infants for changes in heart rate, respiratory rate, and oxygen saturation. Findings from this study indicated increases in heart rate and respiratory rate following noisy events for preterm infants; both preterm and term infants were found to experience decreases in oxygen saturation following noisy events (Hassanein et al., 2013).

Williams and colleagues (2009) calculated correlations between the sound level in the NICU and the heart rate and blood pressure of ELBW neonates. Williams' study (2009) showed

that heart rates of ELBW neonates increased approximately 45-130 seconds after increased sound levels occurred. Mean arterial blood pressure was not associated with higher noise levels (Williams et al., 2009), which suggests that sound levels within a certain range (50-60 dB) may not affect blood pressure. However, an older study conducted by Jurkovicova & Aghova (1989) reported a 10 mmHg increase in blood pressure for approximately five minutes after LBW neonates were exposed to sound levels of 88 dB. This suggests that sound levels above a certain threshold may affect blood pressure in neonates. However, more data is needed to determine if this threshold exists and what noise levels are correlated with changes in blood pressure.

Wharrad and Davis (1997) studied the pattern of heart and respiratory rate responses to sound levels of 80, 90, and 100 dB experienced by preterm and term infants. They found that in both infant groups, an increase in heart rate was proportional to the increase in noise, however, those findings were only statistically significant ($p<0.01$) for 90 and 100 dB in preterm infants (Wharrad & Davis, 1997). This study also found that respiratory rate decreased with an increased noise intensity for all infants, although results were only statistically significant for preterm infants during the 100 dB stimulus (Wharrad & Davis, 1997).

Two earlier studies also showed changes in heart rate with increased noise levels. A study by Segall (1972) revealed that preterm infants responded with an increased heart rate when exposed to white noise at 85 dB while sleeping. Schulman (1969) found that heart rate increased during sleep and wake cycles when high-risk preterm infants were exposed to a 3-second 80 dB noise. High-risk infants were classified as those at increased risk for CNS damage based on the infant's current clinical picture and past medical history (Schulman, 1969).

Increased noise levels can also disrupt preterm infant sleep patterns. Research has demonstrated the importance of protecting sleep and sleep cycles for newborns, as they play a

critical role in early development of the sensory systems (Graven et al., 2008). However, most research in this area has been done with term newborns. One study conducted by Strauch and colleagues (1993) found VLBW infants had fewer crying episodes and spent more time in deep or light sleep during the period when noise levels were reduced.

Some research also suggests that increased noise can alter brain perfusion and possibly contribute to long-term changes in neurological development for preterm infants. In an older study conducted by Long and colleagues (1980), sudden loud noises resulted in agitation and crying of preterm infants, which in turn led to decreased oxygen saturation and increased intracranial pressure (ICP); however, these results were not statistically analyzed. Episodes of apnea have been found to decrease oxygen to the brain, which may worsen long-term neurological development in preterm infants (Pichler et al., 2003). Contrary to these findings, a study by Elser and colleagues (2012) showed that an increase of 5 dB above average ambient sound levels did not significantly affect cerebral oxygenation.

Abou Turk and colleagues (2009) studied the effect of continuous-use earplugs in ELBW infants, which were worn until the infants reached 35 weeks postmenstrual age or were discharged. Infants wearing earplugs (which reduced their noise exposure) scored 15.35 points higher on the Bayley Mental Developmental Index and had head circumferences 2.59 cm larger (compared to infants who did not wear earplugs) at their 18-22 month follow-up (Abou Turk et al., 2009).

In summary, research suggests that increased noise levels can lead to physiological changes including changes in heart rate, blood pressure, respiratory rate, and oxygen saturation in infants in the NICU. These physiological effects may also contribute to decreased brain perfusion and altered neurological development. These possible health effects show the

importance of keeping NICU noise levels within recommended limits in order to provide the best environment for these infants as they continue to develop and transition from life in the womb to the outside world.

Interventions for Reducing NICU Noise Levels

Due to the effects that increased sound levels can have on preterm infants, it is imperative that strategies are implemented to help reduce noise levels in the NICU. One important component of reducing noise in the NICU is to find sources of loud noise specific to the particular unit (Ranganna & Bustani, 2011). Use of commercial dosimeters with visual displays have helped some units reduce noise and may also provide data that can be analyzed; however, unless audio recordings are taken with these measurements, it can be hard to determine what contributing sources of noise correlated with increased sound levels (Ranganna & Bustani, 2011). Reducing alarm noise and phone/pager volumes, as appropriate, can also help reduce noise. Silencing alarms promptly and setting appropriate parameters for alarms on medical equipment can be an easy approach to reducing noise, as well as reduce alarm fatigue from staff (Ranganna & Bustani, 2011). Some units have found that implementation of quiet hours reduced crying and increased sleep for neonates during that period of time (Strauch et al., 1993). Also, educational programs can help increase staff awareness and should be based on interventions specific to the unit (Ranganna & Bustani, 2011).

Wang and colleagues (2014) found that use of sound level meters providing direct audit and visual feedback of noise levels significantly reduced the percentage of noise above 50 dB after installation in the NICU. The meters used in this study displayed red when sound levels were at or above the threshold of 50 dB, displayed yellow when less than 5 dB below threshold, and were green when greater than 5 dB below threshold (Wang et al., 2014). The meters were

originally set at a 45 dB threshold, but continually displayed red and showed little reduction in noise (Wang et al., 2014). There was no significant difference in the mean sound levels with use of these meters, which the authors attributed to high background noise from the HVAC system (Wang et al., 2014). Results from this study showed that noise meters providing direct information and visual feedback and distinguish between louder and quieter periods are most effective. These researchers also recommend setting the thresholds on these meters to accommodate background levels present in each NICU (Wang et al., 2014).

A study conducted at the Children's Hospital of Florida and Benefis Healthcare attempted to reduce sound levels in their NICU through implementation of a staff education program that taught strategies in noise reduction specific to their unit, implementation of quiet hours, as well as minor design modifications including padding cabinet door latches, quieter trash cans, and discontinuing use of the intercom system (Liu, 2010). Despite implementation of these interventions, these two healthcare organizations saw no reduction in sound level measurements compared to baseline (Liu, 2010). However, the two organizations used in this study had lower mean and median sound levels compared to other NICUs implementing changes; the authors mentioned that self-selection bias may have present due to the high motivation of these two organizations to decrease excessive stimulation from the start of their study (Liu, 2010).

Methods

In 2013, the co-chair of the Developmental Care Coach committee at Duke University Hospital's (DUH's) Intensive Care Nursery (ICN) requested sound level measurement by Duke's Occupational and Environmental Safety Office (OESO). The noise data collected by OESO was shared with the Developmental Care Coach committee and revealed that noise levels in the ICN

were above the recommended limits. The committee had hoped to invest in sound level display equipment (SoundEar product) which would immediately notify staff (by illuminating) when levels were too loud. Use of this equipment would have also helped staff identify major noise contributors in the ICN by linking activities with increased noise levels. Due to budget constraints the sound level equipment was not purchased, but the committee remained committed to reducing noise levels in the ICN. Feeding and IV pump alarms, as well as staff-generated noise, were identified as some of the major contributors to increased noise levels that could be addressed through simple interventions. These interventions included reducing all feeding pump alarms, educating staff on reducing IV pump alarms, and implementing a 2-hour daily Quiet Time.

Study Setting

In order to assess the effectiveness of reducing alarm volumes on select equipment (feeding and IV pumps) and implementation of a 2-hour daily Quiet Time, a study was conducted in DUH's ICN measuring sound levels before and after each intervention. Duke's ICN is a 57 bed, level IV nursery that has over 800 admissions per year. This unit focuses on caring for extremely low birth weight infants and their families. Due to concerns of increased noise and the effects it has been shown to have on infants in the ICN, the Developmental Care Coach committee and I examined whether a reduction in feeding and IV pump alarms and implementation of 2-hour daily Quiet Time would reduce overall noise levels. The Developmental Care Coach group (including co-chairs: Cathy Simmons, NNP and Laura Lumsden, NNP) continuously educate ICN nursing staff through a DevelopMe course focused on evidence-based practice care techniques to foster development of infants treated in the ICN. This course has been offered since January 2013 (once per quarter) and is required for all nursing

staff. During our intervention study, 32 staff members were trained in January, 2015. A section of this course includes education on the health effects of increased noise exposure in preterm neonates.

Sound Measurement and Interventions

Sound pressure levels were recorded in the ICN using a Quest 2900 Sound Level Meter, which was calibrated before each measurement session. All measurements were taken using an A-weighted scale and slow response with a 3 dB exchange rate. Sound level measurements were taken in patient rooms and the Provider Area (a central station where providers gather and use computers). In patient rooms, the sound level meter was placed within 12-18 inches of the isolette (on a shelf or attached to the wall), as close to the infant's ear level as possible. In the Provider Area, the sound level meter was placed on a shelf above the provider desks to capture area sound levels. Recorded noise data included an hourly Leq, Lmax, and L10 for each sample in order to compare to recommended levels outlined by White and colleagues (2013). Recommended standards state sound levels in infants rooms should not exceed an hourly Leq of 45 dB, hourly L10 of 50 dB, and Lmax of 65 dB, using the A-weighted scale, slow response (White et al., 2013). In staff work areas, continuous background and operational noise should not exceed an hourly Leq of 50 dB, hourly L10 of 55 dB, and Lmax of 70 dB, also using the A-weighted scale, slow response (White et al., 2013).

Sound level measurements were taken in rooms 5503 (a 4-bed room), 5506 (8-bed room), and in the Provider Area. Hourly Leq, Lmax, and L10 were recorded before any interventions (alarm sound reduction and Quiet Time implementation), after reduction of feeding pump alarms and staff education on reducing IV pump alarms, and again after Quiet Time was implemented. A timeline of measurements and interventions is presented at the end of this section (Figure 1).

Patient room measurements were taken to include Mondays, since this day of the week was indicated to be one of the busiest and nosiest on the unit due to increased team rounding and procedures. The monitor was set-up in patient rooms on Sunday evening, collecting data through that evening, Monday, and part of the following day until it was removed from the unit. Provider area noise data was typically collected later in the week due to restraints in borrowing the Quest Sound Level Meter. All dates and times of measurements can be seen in Figure 1. All collected hourly data was used for data analysis, unless otherwise noted (i.e. some analyses only included hourly means that included Quiet Time hours).

Alarm Reduction Intervention

Prior to implementation of the interventions, Duke OESO personnel and I met with staff from Clinical Engineering to measure the noise levels of current alarm settings on Medex feeding pumps and Alaris IV pumps and assess the sound levels of lower alarm settings. Results of this assessment are included in Tables 1, 2, and 3. The feeding pump alarm levels were taken with the sound level meter inside the open isolette (feeding pump at head of isolette) to simulate the arrangement in patient rooms (Table 1). Feeding pump alarm levels were also taken 3 feet away from the pump to simulate what nurses in the patient's room may hear (Table 2). IV pumps are typically set-up at the end of the isolette in the patient's room (closer to the nurse's central work station), thus sound levels for IV pump alarms were taken at approximately 1 foot away from the pump (Table 3). The default setting for the Medex feeding pump was Level 4 or 5 and could only be changed by Clinical Engineering staff (not user adjusted). The default setting for the Alaris IV pump was Level 5, which could be adjusted by the user; however, after the pump is turned off, it returns to the default setting of Level 5 even if the user has previously reduced the level.

Table 1

Medex Feeding Pump Alarm Levels in Open Isolette

Alarm Level Setting	Sound Level Range (dB)
Level 1	64-65
Level 2	69-70
Level 3	75-76
Level 4	81-82
Level 5	85-86

Note. Pump at head of isolette; sound monitor inside open isolette.

Table 2

Medex Feeding Pump Alarm Levels 3 ft from Pump

Alarm Level Setting	Sound Level Range (dB)
Level 1	54-55
Level 2	64-65
Level 3	70-71
Level 4	77-78
Level 5	82-83

Note. Sound monitor approximately 3 ft away from pump; not inside isolette.

Table 3

Alaris IV Pump Levels

Alarm Level Setting	Sound Level Range (dB)
Level 1	70-71
Level 2	74-75
Level 3	79-80
Level 4	84-85
Level 5	88-89

Note. Sound monitor approximately 1 ft away from pump; not in isolette.

After discussion with ICN management and staff, Clinical Engineering reduced all Medex feeding pump alarms to Level 1 at the beginning of the intervention. This resulted in approximately a 15-20 dB reduction in alarm noise generated by the feeding pumps. Staff education and a unit-specific newsletter article were also provided to staff explaining how to reduce the Alaris IV pump alarms to Level 1-2, along with a reminder that the IV pump alarms would need to be adjusted back to a lower level after being turned off and back on. If staff reduced these alarms, it would result in approximately a 15-19 dB reduction in alarm noise generated by the IV pumps. Maintenance work was also performed during this time on doors at the end of the unit to reduce the speed in which they closed in an attempt to decrease the noise they generated when closing.

Quiet Time Intervention

A 2-hour daily Quiet Time from 12:30-2:30 PM was implemented about one month following reduction of the alarms. This time was chosen by the Developmental Care Coach group to match the Quiet Time and diming lights in the Transitional Care Nursery, a sister unit to the ICN. Lights in the ICN were modified to dim from 12:30-2:30 PM to signify the start/end of Quiet Time to staff and visitors. The ICN staff were instructed to allow infants to rest for these two hours and schedule unnecessary care and procedures around Quiet Time. Nurses' responsibilities included closing curtains to patient rooms and hanging Quiet Time signs during this time to decrease traffic in rooms and minimize patient stimulation. The nursing staff also provided education to parents to help them understand the reason for Quiet Time and encourage their participation.

Study Timeline

A timeline with sound measurement dates for each location, along with dates of intervention implementation, is outlined below in Figure 1.

Baseline Measurements	Location:	Room 5503	Room 5506	Provider Area
	Dates (Times):	Sept 28 (19:54) – Sept 30 (10:54), 2014	Nov 9 (18:53) – Nov 11 (9:53), 2014	Nov 24 (21:28) – Nov 25 (20:28), 2014
Intervention 1: Feeding and IV pump alarm reduction	Date:	Week of Jan 5th, 2015		
Post-Alarm Reduction Intervention Measurements	Location:	Room 5503	Room 5506	Provider Area
	Dates (Times):	Jan 18 (20:48) – Jan 20 (11:48), 2015	Jan 25 (20:54) – Jan 27 (8:54), 2015	Jan 20 (19:55) – Jan 22 (11:55), 2015
Intervention 2: 2-hour Quiet Time implementation	Date:	Started on Feb 16, 2015		
Post-Quiet Time Intervention Measurements	Location:	Room 5503	Room 5506	Provider Area
	Dates (Times):	Feb 22 (20:23) – Feb 24 (11:23), 2015	Feb 16 (00:36) – Feb 17 (13:36), 2015	Feb 19 (18:37) – Feb 21 (10:37), 2015

Figure 1. Timeline for sound measurement data collection and intervention implementation.

Data Analysis

Hourly Leq, L10, and Lmax sound pressure levels (recorded by the Quest 2900 Sound Level Meter) were compared using descriptive statistics. Statistical analysis of these measurements was used to compare hourly noise levels taken before and after the alarm reduction intervention and the Quiet Time intervention. Hourly means were calculated for each metric (Leq, L10, and Lmax) for the entire sampling period, as well as during hours including Quiet Time (12:30 – 2:30 PM). All hourly measurements were compared to White's (2013) recommended sound levels to determine the percentage of time that hourly measurements exceeded the recommendations for Leq, L10, and Lmax. These calculations were done for data collected before interventions (baseline) and after each intervention. A *t*-test was used to

determine statistical significance ($p < 0.05$) for decreases in Leq, L10, or Lmax means in post-intervention measurements compared to baseline.

Results

Baseline Measurements

Baseline hourly Leq means were 55.3 (SD = 1.9) and 55.5 (1.7) dB in patient rooms 5503 and 5506, respectively, and 58.5 (2.8) dB in the provider area (Table 4). All recorded hourly Leq measurements exceeded the recommended Leq of 45 dB or less for infant rooms and 50 dB or less for staff areas (White et al., 2013). Baseline hourly Leq sound levels ranged from 50 – 61.7 dB in patient rooms and from 52.6 – 63.4 dB in the provider area. Baseline hourly Leq measurements during the pre-implementation Quiet Time hours (12:30 AM – 2:30 PM) averaged 54.9 dB in room 5503, 55.0 dB in room 5506, and 60.3 dB in the provider area (Table 7).

Baseline hourly L10 means were 58.1 (2.0) and 57.8 (1.8) dB in patient rooms 5503 and 5506, respectively, and 61.6 (3.2) dB in the provider area (Table 5). All recorded hourly L10 measurements in patient rooms exceeded the recommended L10 of 50 dB or less; the provider area exceeded the recommended L10 of 55 dB 96% of the time (White et al., 2013). Baseline hourly L10 levels ranged from 52.3 – 62.5 dB in patient rooms and from 54.3 – 66.1 dB in the provider area. Baseline hourly L10 measurements during the pre-implementation Quiet Time hours (12:30 AM – 2:30 PM) averaged 58.4 dB in room 5503, 58.0 dB in room 5506, and 63.2 dB in the provider area (Table 7).

Baseline hourly Lmax means were 74.0 (3.0) and 72.0 (3.6) dB in patient rooms 5503 and 5506, respectively, and 75.3 (3.7) dB in the provider area (Table 6). Recorded hourly Lmax measurements in patient rooms exceeded the recommended Lmax of 65 dB or less 100% of the time in room 5503 and 98% of the time in room 5506; all recorded baseline Lmax measurements

in the provider area exceeded the recommendation of 70 dB (White et al., 2013). Baseline hourly Lmax levels ranged from 64.5 – 81.4 dB in patient rooms and from 71.3 – 85.9 dB in the provider area. Baseline hourly Lmax measurements during the pre-implementation Quiet Time hours (12:30 AM – 2:30 PM) averaged 72.6 dB in room 5503, 69.1 dB in room 5506, and 78.2 dB in the provider area (Table 7).

Post-Alarm Reduction Measurements

Post-alarm reduction hourly Leq means were 56.4 (SD = 2.7) and 55.0 (1.9) dB in patient rooms 5503 and 5506, respectively, and 58.3 (2.1) dB in the provider area (Table 4). All recorded hourly Leq measurements post-alarm reduction exceeded the recommended Leq of 45 dB or less for infant rooms and 50 dB or less for staff areas (White et al., 2013). Hourly Leq sound levels ranged from 50.9 – 63.1 dB in patient rooms and from 54.0 – 61.7 dB in the provider area. The Leq measurements following alarm reduction were not substantially different than before alarms were reduced; the largest drop in hourly Leq means was 0.5 dB in room 5506, while room 5503's levels increased by 0.9 dB. The reduction in hourly Leq in room 5506 was not found to be statistically significant ($p=0.23$). The small 0.2 dB noise reduction in the provider area was also not found to be significant ($p=0.83$).

Post-alarm reduction hourly L10 means were 59.2 (3.3) and 57.0 (2.1) dB in patient rooms 5503 and 5506, respectively, and 61.5 (2.6) dB in the provider area (Table 5). All recorded hourly L10 measurements after alarm reduction exceeded the recommended L10 of 50 dB or less for infant rooms and 55 dB of less for staff areas (White et al., 2013). Hourly L10 sound levels ranged from 52.4 – 67.5 dB in patient rooms and from 56.3 – 66.1 dB in the provider area. The L10 measurements following alarm reduction were also not substantially different than before alarms were reduced; the largest drop in hourly L10 means was 0.8 dB in

room 5506, while room 5503's levels increased by 1.1 dB. The reduction in hourly L10 in room 5506 was not found to be statistically significant (p=0.06). The 0.1 dB reduction in the provider area was also not significant (p=0.84).

Post-alarm reduction hourly Lmax means were 74.4 (3.8) and 73.0 (4.2) dB in patient rooms 5503 and 5506, respectively, and 74.8 (2.7) dB in the provider area (Table 6). The recommended L10 of 65 dB or less for infant rooms was exceeded 100% of the time in room 5503 and 95% of the time in room 5506; the provider area exceeded the recommended Lmax of 70 dB of less 100% of the time (White et al., 2013). Hourly Lmax sound levels ranged from 63.8 – 84.1 dB in patient rooms and from 70.4 – 80.8 dB in the provider area. The Lmax measurements following alarm reduction were also not substantially different than before alarms were reduced; levels in patient rooms increased by 0.4 – 1.0 dB and dropped by only 0.5 dB in the provider area. The reduction in noise levels in the provider area was not found to be statistically significant (p=0.56). This suggests that feeding pump and IV pump alarms may not be the major contributors to noise since we did not see a substantial decrease in sound levels.

Post-Quiet Time Implementation Measurements

During the first week of Quiet Time implementation, hourly Leq means were 57.8 (SD = 2.1) and 58.0 (1.2) dB in patient rooms 5503 and 5506, respectively, and 56.8 (2.3) dB in the provider area (Table 4). All recorded hourly Leq measurements exceeded the recommended Leq of 45 dB or less for infant rooms and 50 dB or less for staff areas (White et al., 2013). Post-Quiet Time hourly Leq sound levels ranged from 53.3 – 63.5 dB in patient rooms and from 52.3 – 61.1 dB in the provider area. Leq hourly means increased in patient rooms by 2.5 dB post-Quiet Time. The provider area hourly Leq mean decreased by 1.7 dB after Quiet Time was implemented, which was statistically significant (p=0.02). Hourly Leq measurements during Quiet Time hours

(12:30 AM – 2:30 PM) averaged 59.9 dB in room 5503, 58.0 dB in room 5506, and 57.4 dB in the provider area (Table 7). Both patient rooms saw increased sound levels from baseline during these hours. Hourly Leq means during Quiet Time hours increased in room 5503 by 5.0 dB and in room 5506 by 3.0 dB. Hourly Leq means in the provider area during Quiet Time hours decreased by 2.9 dB compared to baseline, however, this decrease was not statistically significant (p=0.21).

During the first week of Quiet Time implementation, hourly L10 means were 60.3 (2.5) and 60.2 (1.5) dB in patient rooms 5503 and 5506, respectively, and 59.6 (2.8) dB in the provider area (Table 5). All recorded hourly L10 measurements in patient rooms exceeded the recommended L10 of 50 dB or less for infant rooms; the provider area exceeded the recommendation of 55 dB or less 95% of the time (White et al., 2013). Post-Quiet Time hourly L10 means ranged from 54.1 – 67.6 dB in patient rooms and from 53.1 – 64.4 dB in the provider area. Post-Quiet Time hourly L10 means increased in room 5503 and 5506 by 2.2 and 3.6 dB, respectively. The provider area hourly L10 mean decreased by 2.0 dB after Quiet Time was implemented, which was statistically significant (p=0.01).Hourly L10 measurements during Quiet Time hours (12:30 AM – 2:30 PM) averaged 61.5 dB in room 5503, 59.9 dB in room 5506, and 60.6 dB in the provider area (Table 7). Both patient rooms saw increased sound levels from baseline during these hours. Hourly L10 means increased in room 5503 by 2.9 dB and in room 5506 by 1.9 dB. Hourly L10 means in the provider area decreased by 2.6 dB compared to baseline, however, this decrease was not statistically significant (p=0.22).

During the first week of Quiet Time implementation, hourly Lmax means were 75.2 (3.6) and 74.8 (3.3) dB in patient rooms 5503 and 5506, respectively, and 73.0 (2.8) dB in the provider area (Table 6). All recorded hourly Lmax measurements in patient rooms exceeded the

recommended Lmax of 65 dB or less for infant rooms; the provider area exceeded the recommendation of 70 dB or less 88% of the time (White et al., 2013). Post-Quiet Time hourly Lmax means ranged from 69.0 – 82.8 dB in patient rooms and from 69.1 – 81.1 dB in the provider area. Post-Quiet Time hourly Lmax means increased in room 5503 and 5506 by 1.2 and 2.8 dB, respectively. The provider area hourly Lmax mean decreased by 2.3 dB after Quiet Time was implemented, which was statistically significant (p=0.01).Hourly Lmax measurements during Quiet Time hours (12:30 – 14:30) averaged 74.8 dB in room 5503, 78.2 dB in room 5506, and 73.8 dB in the provider area (Table 7). Both patient rooms saw increased sound levels from baseline during these hours; hourly Lmax means increased in room 5503 by 2.2 dB and in room 5506 by 9.1 dB. Hourly Lmax means in the provider area decreased by 4.4 dB compared to baseline during Quiet Time hours, however, this reduction was not statistically significant (p=0.40).

Table 4

Hourly Leq Mean (Entire Sampling Period)

Measurement Parameter	Room 5503	Room 5506	Provider Area
Baseline Leq	55.3	55.5	58.5
Leq post-alarm reduction	56.4	55.0	58.3
Leq post-Quiet Time implementation	57.8	58.0	56.8

Note. All values are reported in dB.

Table 5

Hourly L10 Mean (Entire Sampling Period)

Measurement Parameter	Room 5503	Room 5506	Provider Area
Baseline L10	58.1	57.8	61.6
L10 post-alarm reduction	59.2	57.0	61.5
L10 post-Quiet Time implementation	60.3	60.2	59.6

Note. All values are reported in dB.

Table 6

Hourly Lmax Mean (Entire Sampling Period)

Measurement Parameter	Room 5503	Room 5506	Provider Area
Baseline Lmax	74.0	72.0	75.3
Lmax post-alarm reduction	74.4	73.0	74.8
Lmax post-Quiet Time implementation	75.2	74.8	73.0

Note. All values are reported in dB.

Table 7

Hourly Mean During Quiet Time Hours (12:30-14:30)

Measurement Parameter	Room 5503	Room 5506	Provider Area
Baseline Leq	54.9	55.0	60.3
Leq post-Quiet Time implementation	59.9	58.0	57.4
Baseline L10	58.4	58.0	63.2
L10 post-Quiet Time implementation	61.5	59.9	60.6
Baseline Lmax	72.6	69.1	78.2
Lmax post-Quiet Time implementation	74.8	78.2	73.8

Note. All values are reported in dB.

Discussion

All baseline noise levels in patient rooms and the provider area were found to exceed White's (2013) recommended noise levels 100% of the time, with the exception of L10 means in the provider area (exceeded 96% of the time). Upon comparing the baseline and post-alarm reduction measurements, there was minimal to no reduction in noise levels in the patient rooms for all measurement parameters (Leq, L10, and Lmax). The small reductions seen in room 5506 were not statistically significant for Leq and L10 ($p = 0.23$ and 0.06, respectively). Reductions seen in the provider area after alarm reduction were also not statistically significant for Leq, L10, and Lmax ($p = 0.83$, 0.84, and 0.56, respectively). Even though feeding pump and IV pump alarms contribute to noise in these areas, our data suggests there could be other major noise

contributors. After comparing baseline and post-Quiet Time implementation measurements for patient rooms, all measurement parameters showed an increase in noise levels, which was an unexpected finding. Possible explanations for this include increased noisy equipment in these rooms (specifically ventilators), increased use of the intercom system, and an increase in staff-generated noise due to procedures; however, because data was not collected on these variables it is unclear what actually contributed to the increased noise levels observed. Discussion with staff during this time period suggested that there was an increase in infants on ventilators in these rooms during post-Quiet Time data collection, though this explanation was unable to be confirmed. It is also likely that there are other unidentified major noise contributors that should be targets for future interventions. In order to identify the major contributors of noise, data should be collected in a way that connects specific activities to increased noise levels. This could be achieved through use of a sound level display (e.g., product made by SoundEar) which allows the user to set specific sound levels that display a certain color or warning when the room exceeds the set level. Staff in these rooms can identify what activities are occurring when the display shows that the set noise level is being exceeded. Once noisy activities are identified, interventions can be targeted to reduce sound levels specific to those activities. Noisy activities could also be identified through use of audio and/or video recording that is synchronized to sound level data collection, though this could be time-consuming for the data collector to review and analyze.

On a positive note, data comparing baseline and post-Quiet Time implementation measurements for the provider area suggests that noise may have been reduced in this staff area due to the noise reduction focus and Quiet Time practice. All reductions in noise after Quiet Time implementation (from data collected over the entire sampling period) were statistically

significant with p-values of 0.02, 0.01, and 0.01 for Leq, L10 and Lmax, respectively. Even though reductions also appear substantial when comparing the baseline and post-intervention means only during Quiet Time hours (Table 6), none of these were statistically significant (p-values of 0.21, 0.22, and 0.40 for Leq, L10, and Lmax, respectively). This is likely due to the small sample size since only the hours including Quiet Time were included in this analysis. The reduction in sound levels in the Provider Area was expected since there are fewer sources of noise (less alarming medical equipment), suggesting that employee-generated noise is one of the major noise contributors in this area. A sound level display or recording device could also be used in this area to help identify other noise sources to target future interventions.

Limitations

Since only sound pressure level data was collected in each area, there are many other variables that could have contributed to noise that we did not collect data on in this study. These variables include: the number and types of equipment in each area that produce noise (e.g., ventilators, monitors), number of audible alarms from equipment, information on the number and types of noisy procedures and events in the room during the sampling period, staff compliance on reducing IV pump alarms, and number of times the intercom system was used in the patient rooms. Without having information on these variables, caution must be used when interpreting our results as these other variables could have affected the sound levels in these areas and influenced the overall noise measurements when comparing levels before and after interventions. A more comprehensive study including data on these other variables could help the ICN identify which variables are the largest contributors to noise to better target their noise reduction interventions moving forward.

Ambient sound pressure levels only give us information on what the noise levels are in the room and may not accurately reflect the noise that infants in the NICU truly experience. A sound level meter that could be placed in the isolette at the infant's ear level would provide a more accurate representation of the noise experienced by the infant. However, for purposes of this study and in order to compare to NICU noise level recommendations, only area noise levels were collected in patient rooms.

Sound level data collected for the Provider Area was not recorded on the same day of the week each time due to the constraints of borrowing the Quest Sound Level Meter from Duke's OESO. Samples in the Provider Area were taken on Monday – Tuesday for baseline, Tuesday – Thursday for post-alarm reduction, and Thursday – Saturday for post-Quiet Time implementation. Collecting data on different days of the week could have affected results if some days of the week are noisier than others; however, according to the staff, Monday's were considered to be the noisiest. Since Monday was included in our baseline measurement, but not during sampling after each intervention, this could have biased our findings towards a reduction in noise after interventions were implemented.

Nursing Implications and Future Research

Investigating nursing interventions on best practices to reduce noise in the NICU will help nurses continue to create a more healing environment for this patient population, as well as enhance infants' growth and development. Further research is needed to determine which interventions best reduce noise so nurses can advocate for these changes and understand how to implement them on their unit. Our study suggests that only measuring sound pressure levels provides limited value. Before possible interventions are determined, it is recommended that a noise survey be conducted to identify all major noise contributors in order to best target noise

reduction interventions. A visual sound level display or recording device could also be used in conjunction with sound level monitoring to help determine major noise contributors. Not only should future research include collection of data on other noise-causing variables in the NICU, but also identify effective, low-cost interventions for reducing noise levels that can be implemented when a costly NICU redesign is not feasible.

Continued research also needs to be done to more clearly identify correlations between physiological effects and increased noise exposure in preterm neonates. As part of this research, noise monitoring should be done to best represent the true exposure of the neonate by taking readings inside the isolette and at the infant's ear level.

Research on generalizable noise reduction strategies in the NICU can be somewhat difficult due to the variety of NICU designs and manufacturers utilized for medical equipment in this setting. One approach to helping reduce unnecessary alarm noise could be development of an interdisciplinary team that includes nurses and medical equipment manufacturers. This type of team could work together to design isolettes that diminish ambient noise, which could reduce the infant's noise exposure in the isolette. However, it is best to reduce noise at the source, so this team could also identify ways to eliminate unnecessary alarms and decrease other equipment noise through settings that could be customized by the individual unit. With The Joint Commission's (2013) national patient safety goal of reducing alarm noise and fatigue, this type of interdisciplinary work could be beneficial across all medical settings. Hospitals are already required by The Joint Commission to "identify the most important alarms to manage based on their own internal situations" and will be required to create and implement policies related to alarm reduction by January of 2016 (The Joint Commission, 2013). Continued research on best strategies for alarm reduction, especially for existing NICUs, is not only important to comply

with The Joint Commission goals, but is also important for continued patient safety and improved health outcomes for infants.

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Appendix A

Descriptive Statistics Data Table (Entire Sampling Period)

	N	Mean	Median	Std Deviation	Sample Variance
Room 5503					
Baseline Leq	40	55.3	55.3	1.9	3.6
Leq post-alarm reduction	40	56.4	55.8	2.7	7.5
Leq post-Quiet Time implementation	40	57.8	57.7	2.1	4.2
Baseline L10	40	58.1	58.5	2.0	3.9
L10 post-alarm reduction	40	59.2	58.3	3.3	11.0
L10 post-Quiet Time implementation	40	60.3	59.9	2.5	6.2
Baseline Lmax	40	74.0	74.1	3.0	9.0
Lmax post-alarm reduction	40	74.4	74.4	3.8	14.3
Lmax post-Quiet Time implementation	40	75.2	75.1	3.6	13.0
Room 5506					
Baseline Leq	40	55.5	55.4	1.7	2.8
Leq post-alarm reduction	37	55.0	55.0	1.9	3.8
Leq post-Quiet Time implementation	38	58.0	58.0	1.2	1.5
Baseline L10	40	57.8	57.8	1.8	3.3
L10 post-alarm reduction	37	57.0	57.0	2.1	4.6
L10 post-Quiet Time implementation	38	60.2	60.2	1.5	2.3
Baseline Lmax	40	72.0	72.0	3.6	13.0
Lmax post-alarm reduction	37	73.0	73.4	4.2	17.4
Lmax post-Quiet Time implementation	38	74.8	74.5	3.3	10.7
Provider Area					
Baseline Leq	24	58.5	59.0	2.8	8.0
Leq post-alarm reduction	41	58.3	58.5	2.1	4.6
Leq post-Quiet Time implementation	41	56.8	56.7	2.3	5.2
Baseline L10	24	61.6	62.4	3.2	10.0
L10 post-alarm reduction	41	61.5	61.5	2.6	6.6
L10 post-Quiet Time implementation	41	59.6	59.6	2.8	7.7
Baseline Lmax	24	75.3	74.6	3.7	13.5
Lmax post-alarm reduction	41	74.8	75.1	2.7	7.1
Lmax post-Quiet Time implementation	41	73.0	72.4	2.8	7.8

Note. All means are reported in dB.

Appendix B

Differences in Mean Sound Levels from Baseline

	Entire Sampling Period		Quiet Time Hours Only	
	Difference in Means from Baseline	*p* value	Difference in Means from Baseline	*p* value
Room 5503				
Leq post-alarm reduction	+1.1			
Leq post-Quiet Time implementation	+2.5		+5.0	
L10 post-alarm reduction	+1.1			
L10 post-Quiet Time implementation	+2.2		+3.1	
Lmax post-alarm reduction	+0.4			
Lmax post-Quiet Time implementation	+1.2		+2.2	
Room 5506				
Leq post-alarm reduction	0.5	0.23		
Leq post-Quiet Time implementation	+2.5		+3.0	
L10 post-alarm reduction	0.8	0.06		
L10 post-Quiet Time implementation	+2.4		+1.9	
Lmax post-alarm reduction	+1.0			
Lmax post-Quiet Time implementation	+2.8		+9.1	
Provider Area				
Leq post-alarm reduction	0.2	0.83		
Leq post-Quiet Time implementation	1.7	**0.02**	2.9	0.21
L10 post-alarm reduction	0.1	0.84		
L10 post-Quiet Time implementation	2.0	**0.01**	2.6	0.22
Lmax post-alarm reduction	0.5	0.56		
Lmax post-Quiet Time implementation	2.3	**0.01**	4.4	0.40

Note. All differences reported in dB; *p* values $\leq$ 0.05 are bolded. A "+" in front of the value indicates an increase in mean levels from baseline. Statistical significance was only analyzed when mean values decreased from baseline; a *t*-test was used to determine significance between baseline and post-intervention levels.